An PC-based Airborne SAR Baseband System

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Abstract— This paper presents the development work of a PC-based airborne SAR baseband system that integrates commercial off-the-shelf Arbitrary Waveform Generator (AWG) and high-speed digitizer, and a custom-designed Timing and Control Unit (TCU). The proposed system is general purpose, in which the critical operating parameters such as waveform modulation format, baseband bandwidth, pulse width, pulse repetition frequency, and all the relevant timing and control signals are re-configurable in real-time. As a brief functional summary of the system, it can, i) generates 2-channel (I & Q) of 1.2 GHz (maximum) bandwidth chirp signal with its pulse width ranged from 0.5 us to 100 µs, ii) able to digitize 2-channel (I & Q) of 1 GHz (maximum) bandwidth chirp echoes with on-board 4 G-Samples of recording buffer, and iii) generate accurate and precise timing and control signals with timing resolution of 10 ns. The system is currently deployed as the baseband and control system for Josaphat Microwave Remote Sensing Laboratory (JMRSL) C band airborne full polarimetric Circularly Polarized Synthetic Aperture Radar (CP-SAR) sensor built for Earth surface, environmental, and disaster monitoring.

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is a famous tool in microwave remote sensing due to its capability of all-weather and day-to-night time operation [1, 2]. SAR uses microwave signal and are robust in the face of unfavorable weather conditions and its cloud cover, haze, and dust and even rain penetration capabilities [3, 4]. In general, an SAR system is composed of several major sub-systems, namely, the Radio Frequency (RF) transmitter and RF receiver, the antenna, and the baseband system [5]. The baseband system holds a significant role that, i) generates the required modulated baseband signal, ii) digitize the stream of collected baseband echoes, and iii) synchronize the timing and control the operating sequence of the entire SAR system using proper timing and control signals.

Josaphat Microwave Remote Sensing Laboratory (JMRSL) from Center for Environmental Remote Sensing (CEReS), Chiba University is currently developing dual-band airborne (C/X) full polarimetric Circularly Polarized Synthetic Aperture Radar (CP-SAR) system for disaster and environmental monitoring [6]. The development time incurred in a SAR baseband system development is usually long, for the sake of the stringent requirements in the hardware specifications such as the high data sampling and transfer rate in the digitizer, the high time-bandwidth product (high bandwidth and narrow pulse width) of the baseband signal in the waveform synthesizer, and the high accuracy and precision of the timing and control signals. In order to reduce the development time, it is therefore proposed in this paper a general purpose SAR baseband unit that is built from commercial off-the-shelf electronics with minimal hardware level design. Currently, the baseband system is used in JMRSL C band CP-SAR system. In future, the system will be upgraded for use in dual band (C/X) full polarimetric CP-SAR system.

This paper presents the development of the SAR baseband unit. The paper first presents the proposed system architecture and its specifications in Section 2, followed by the discussion on system integration in Section 3. Section 4 shows the tests done and presents the experiment results. Finally, the work is concluded in Section 5.

2. SYSTEM ARCHITECTURE AND SPECIFICATIONS

Figure 1 shows the top-level hardware architecture of JMRSL C band CP-SAR system. In general, there are 4 sub-subsystems, namely, Power Distribution Unit (PDU), Inertial Nagivation System (INS), SAR Baseband Unit, and Radio Frequency (RF) sub-system. The SAR baseband unit is a centralized control and processing module that controls and synchronizes the operation of the entire SAR system. Figure 2 depicts the system architecture of the proposed SAR baseband unit. The baseband unit handles several important processes in the SAR system, which are,

(i) To generate the baseband waveform (chirp generation).

(ii) To digitize the collected echoes at RF receiver output.

(iii) To provide a mass storage space for temporarily storage of huge amount of data.

(iv) To generate re-configurable, accurate and precise timing and control signals for other sub-modules in the SAR system.

(v) To control and synchronize the operation of the entire SAR system, which includes the RF sub-system.

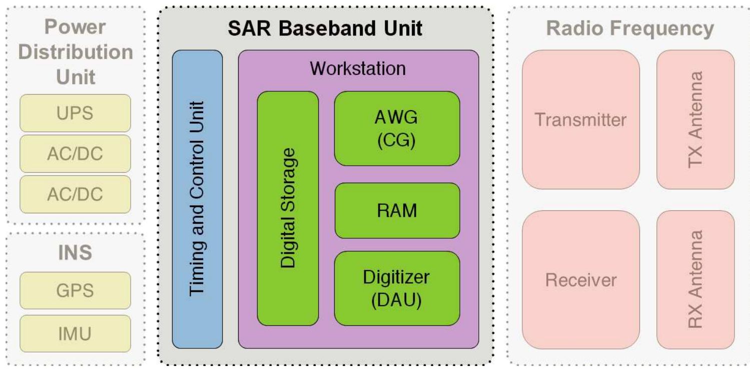


Figure 1: Top level hardware architecture of SAR system.

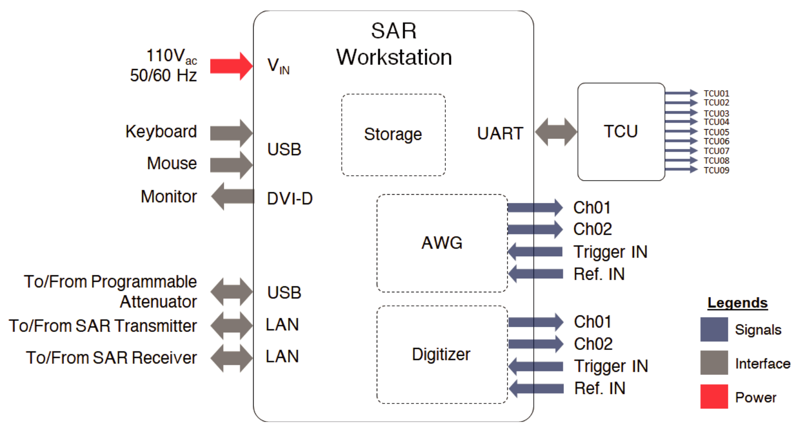


Figure 2: System architecture of the SAR baseband unit.

The SAR baseband unit is built from a workstation that consist of, i) an Arbitrary Waveform Generator (AWG), ii) a high-speed digitizer, and iii) two units of high-speed Solid-State Drive (SSD), and, a Timing and Control Unit (TCU). All of the components except the TCU are commercial off-the-shelf hardware product, whereby the TCU is a custom-designed system using Field Programmable Gate Array (FPGA). The subsequent text in this section gives a brief description of each component. Table 1 lists the specifications of each component.

2.1. Workstation

The centralized controller for the SAR baseband unit is Dell Precision R7910 rack mount workstation as shown in Figure 3(a). The workstation has two Intel® Xeon® processor, 16 Giga-Bytes of RAM, and is equipped with 2 units of 2 TB V-NAND SSD. It can support up-to 7 PCIe form factor peripherals which will be very helpful for future upgrade in the baseband system. Figure 2 shows the front view and the rear view of the workstation.

2.2. Chirp Generator

Chirp generator is one of the important component that generates the required baseband chirp signal. The key parameter of chirp generator is its synthesizable bandwidth that determines the range resolution of the SAR system [7–9]. The proposed chirp generator hardware in the baseband unit is Signatec PXDAC4800D-DP AWG and Figure 3(b) shows the pictorial view of the AWG. The Signatec PXDAC4800 is an exceptionally high-speed four channels Digital to Analog Conversion

Table 1: Hardware specifications.

Module	Specification	Value
Workstation	Processor	Dual Intel Xeon E5-2603 v4 (1.7 GHz)
	Memory	16 GB (4 × 4 GB) 2400 MHz DDR4 RDIMM ECC
	Storage	2 × 2 TB SATA 6GB/s SSD
Chirp Generator	Output channel	4
	Sampling rate	1.2 GSPS for 2 channels 600 MSPS for 4 channels
	Resolution	14-bits
	Memory depth	1 GB DDR2 RAM
	Analog bandwidth	590 MHz
	Output voltage	400 mV to 1470 mV (50 Ω)
	Interface	900 MB/s via 8-lan PCIe bus
Digitizer	Output channel	2
	Sampling rate	1 GSPS
	Resolution	16-bit
	Memory depth	4 GS (8GB)
	Analog bandwidth	700 MHz
	Interface	4+ GB/s 8-lane PCIE Gen3
Timing and Control Unit	Output channel	9
	Timing precision	4 ns
	Communication module f_{clk}	50 MHz
	Timing module f_{clk}	250 MHz
	I/O Standard	+3.3V LVTTL
	FPGA chipset	EP4CE22F17C6N

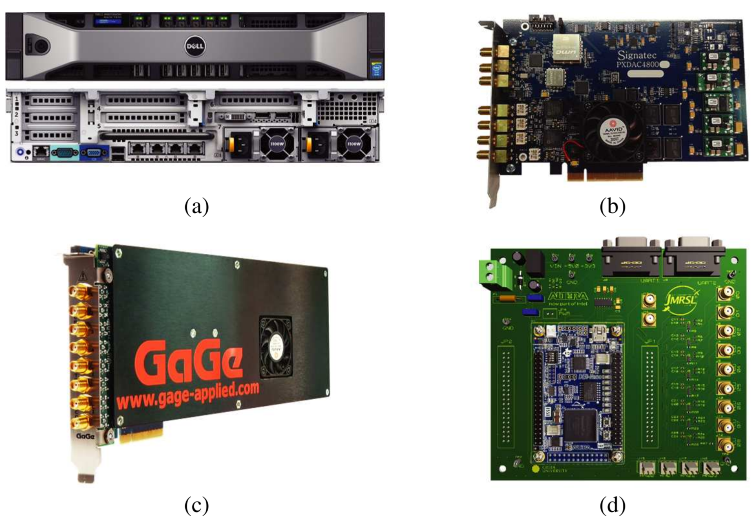


Figure 3: Components in SAR baseband unit: (a) Workstation as the centralized controller, (b) PXDAC4800D-DP AWG for chirp waveform synthesis, (c) Gage RazorMax CSE161G2 high-speed digitizer for data acquisition, (d) custom designed timing and control unit.

(DAC) board with each DAC can output data at a maximum real rate of 1.2 GSPS at 14-bit for two channels or at 8-bit for four channels, or 600 MSPS at 14-bit for four channels. Each output signal has a bandwidth of up to 400 MHz for AC-Coupled configuration or up to 590 MHz for DC-Coupled configuration. Output waveforms may be per-trigger or continuously looped from the on-board 1 Gigabyte memory.

2.3. High Speed Data Acquisition Unit

In SAR, data acquisition unit digitizes all the collected baseband echoes and stores them in the mass storage device for latter post-processing. In a high bandwidth SAR system (few hundreds MHz of bandwidth), a high sampling rate digitizer with high data transfer rate to the mass storage device is essential so that all collected echoes can be fully captured. The digitizer features unprecedented speed and resolution with two 16-bit channels at 1 GS/s bandwidth, with PCIe data streaming rates at 4+ GB/s. The digitizer has on-board 4 GS (8 GB) of sample memory and can supports multiple record recording that allows ultra-rapid repetitive waveform acquisition. Furthermore, re-arming of trigger circuitry is done in hardware with no software intervention required. Figure 3(c) shows the pictorial view of the high-speed digitizer.

2.4. Timing and Control Unit (TCU)

TCU is one of the essential sub-system in a typical SAR system. In the actual SAR system operation, TCU generates all the relevant timing signals to control and synchronize other sub-systems so that the clock coherency among the sub-systems can be retained. A custom TCU using Field Programmable Gate Array (FPGA) is designed for the SAR baseband unit. Figure 3(d) shows the assembled TCU. The TCU can generate 9 channels of extremely accurate and precise control signals with the timing precision of 4 ns. The timing information for every channels are re-configurable in real-time by sending the appropriate command string to the TCU through its serial communication interface.

3. SYSTEM INTEGRATION

The AWG and the high-speed digitizer are installed in the workstation. Meanwhile, the TCU is placed as a part of the Power and Control Unit (PCU) together with the power distribution sub-system. Then, the SAR baseband unit is integrated into the JMRSL C Band CP-SAR system. Figure 4 shows the integrated SAR electronic system with the SAR baseband unit. A centralized Graphical User Interface (GUI) control software is developed for controlling the individual hardware (AWG, digitizer and TCU) and for data acquisition. Figure 5 shows the screenshot of the control software showing, i) the waveform generation panel for configuring the chirp parameters and controlling the chirp generation, ii) the TCU panel for configuring the timing information, and iii) the data acquisition panel for acquiring large records of echoes.

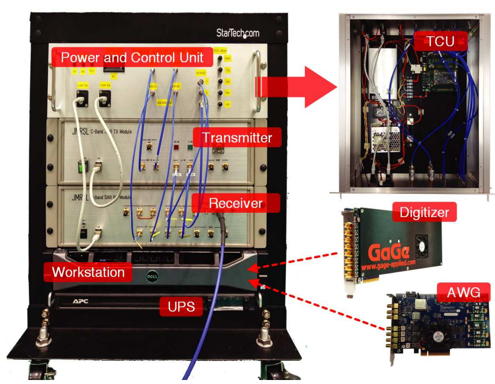


Figure 4: Integration of SAR baseband unit into JMRSL C band CP-SAR system.

4. SYSTEM TESTS AND RESULTS

A series of tests were conducted on the integrated SAR system to validate the functionality of each sub-module. Figure 6(a) and Figure 6(b) show the recorded timing signals and chirp waveforms using Rohde & Schwarz RTO 1044 digital oscilloscope. The plots show that the TCU and the chirp generator can generate accurate timing signals and chirp waveform. Next, the waveform generated by the chirp generator was looped back to the input of the digitizer and a sample of the waveform was recorded. Then, the recorded data was imported into Matlab® environment and the frequency spectrum of the chirp was plotted. To further validate the functionality of the system, the recorded chirp signal was matched filtered with the ideal reference chirp waveform (range compression) and

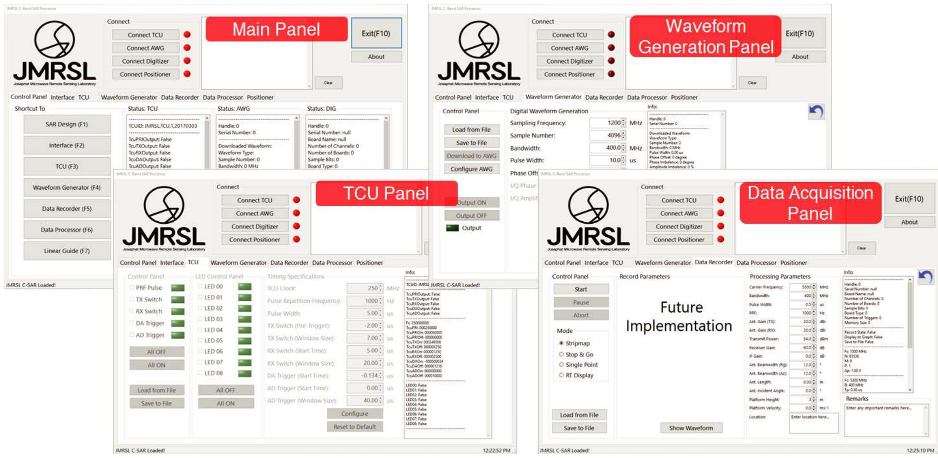


Figure 5: GUI control software for SAR baseband unit.

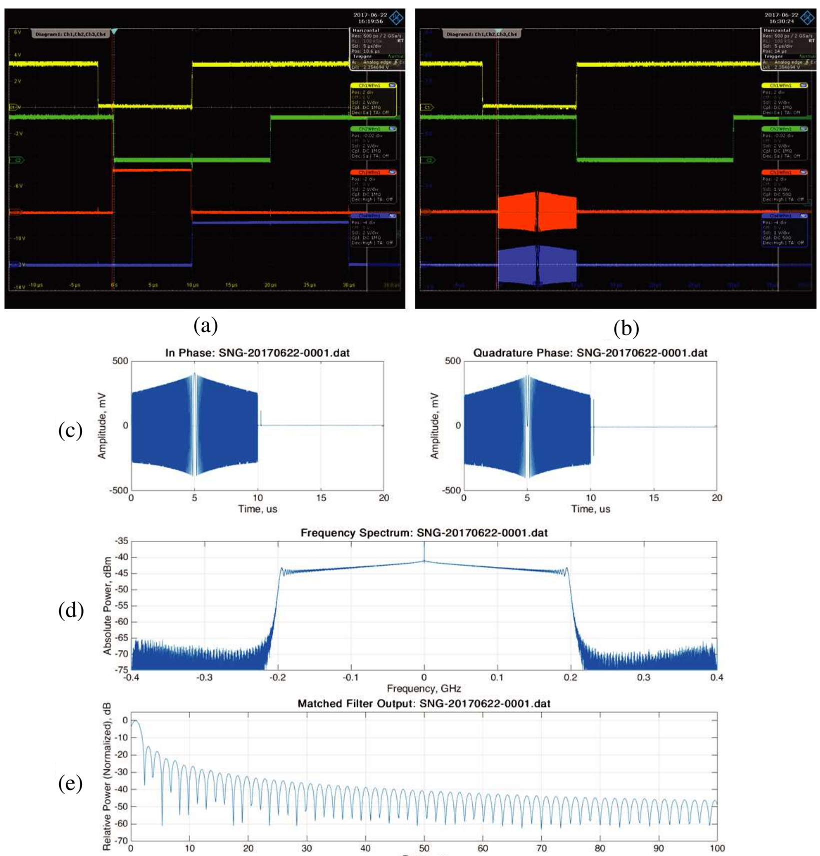


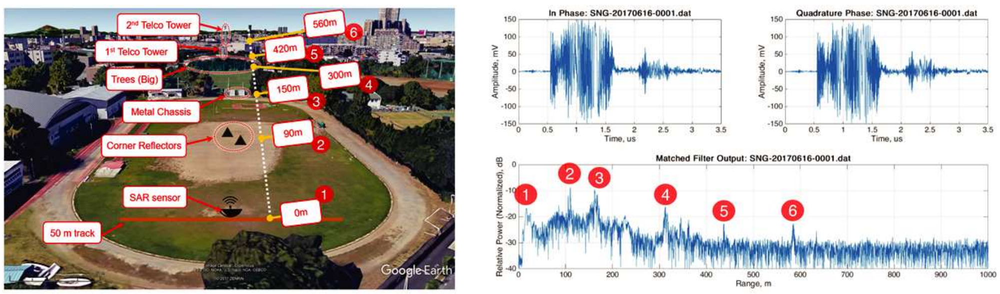
Figure 6: SAR baseband unit sub-module testing: (a) Timing and control signals from TCU, (b) Chirp waveform (I in orange and Q in blue), (c) Recorded loopback signal in time domain, (d) Spectrum of the recorded chirp, and (d) Matched filter output of the recorded chirp.

the output of the range compression was plotted. Figure 6(c) shows the recorded loopback signal in time domain, Figure 6(d) shows the plotted spectrum and Figure 6(e) shows the matched filter output. The spectrum plot shows superior clean spectrum while the matched filter output verified the functionality of the SAR baseband unit.

Before the actual flight test, several rounds of ground test were conducted in Chiba University, Japan, with the purpose to validate the functionality of the entire SAR system. In the system range tests, two trihedral corner reflectors were put at 90 meters away from the sensor and the echoes were recorded. Figure 7 shows the range compressed plot of the echoes. The plot shows that the system can precisely detects the trihedral corner reflectors (Point 2), also some permanent scatterers that are located behind the reflectors, such as the metal enclosure (Point 3), large trees (Point 4), and telecommunication towers (Point 5 and Point 6) that are located approximately 400 meters and 560 meters away from the SAR system.

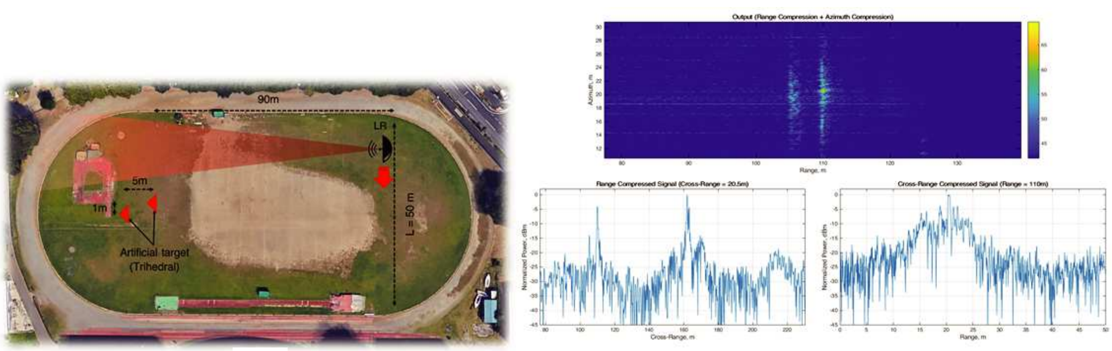
After the range test, ground based imaging test was conducted to test the imaging capability of the SAR system. Figure 8(a) shows the test setup on the same field. In the imaging test, a 50 meters rail was assembled on the field and the SAR system was placed at the left end of the rail. The antennas were elevated to 2 meters height above the ground and were pointing toward the scene. Then, using a 1-axis robot, the system moved 50 cm toward the right end of the rail, stopped, scanned, and the echoes were recorded. The measurement was repeated for 1001 times (Stop-N-Go, 1001 azimuth points, 50 m total azimuth length) so that the scan covers more than one synthetic length for targets that are located in the middle of the field. The collected 2-dimensional data was processed and the acquired SAR image is shown in Figure 8(b).

Next, the performance of the SAR system (with the SAR baseband unit) was further tested



(a) (b)

Figure 7: Range test: (a) test setup, (b) results.



(a) (b)

Figure 8: Ground based imaging test: (a) test setup, (b) results.

(a) (b) (c)

Figure 9: Focused SAr image (polarization: RHCP transmit, LHCP receive): (a) the entire scene, (b) enlarged image of the green rectangle area in (a), (c) optical image extracted from Google earth™.

in JMRSL Hinotori-C2 flight mission. The mission was held from 3 March to 16 March 2018, in Makassar, Indonesia with the complete SAR system was installed in a CASA/IPTN CN235-MPA aircraft. The main objective of the flight test was to validate the functionality of the SAR system and to acquire circularly polarized SAR images that cover different types of natural and artificial targets such as calibration reflectors, man-made buildings, water body, homogeneous rainforest area. In the flight mission, three rounds of flight test were successfully conducted. Figure 9 shows one of the focused SAR image, the enlarged SAR image of a specific area, and its optical image extracted from Google Earth™. The obtained high quality SAR images from the flight mission has proven that the new CP-SAR system, with the baseband unit proposed in this paper, is working well.

5. CONCLUSION

A general purpose SAR baseband unit has been designed and developed. The baseband system is able to, i) generate high time bandwidth product chirp signal, ii) generate high precision and accuracy timing and control signals, and iii) record high bandwidth chirp echoes for large range and azimuth samples. The system parameters of the several functionality test of the baseband unit were carried out through ground test and flight test, and the test results verified the performance of the proposed system. The system is currently being used as the baseband unit of JMRSL C band full polarimetric airborne SAR system and in future, the system will be upgraded to support JMRSL dual band (C/X) full polarimetric airborne SAR system.

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